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November 21, 2016

VIA ELECTRONIC FILING

Marlene H. Dortch, Secretary
Federal Communications Commission
445 12th Street, S.W.
Washington, D.C. 20554

Re: Written *Ex Parte* Notice, GN Docket No. 14-177, IB Docket Nos. 15-256 and 97-95; RM-11664; and WT Docket No. 10-112

Dear Ms. Dortch:

The Boeing Company (“Boeing”), through its counsel, hereby responds to certain of the reply comments that were filed on October 31, 2016 regarding the ability of non-geostationary satellite orbit (“NGSO”) systems to operate in the 37.5-40.0 (“37/39”) GHz band using power levels that may reach up to the power flux density (“PFD”) limits maintained by the International Telecommunication Union (“ITU”)¹ and maintained by the Commission in Section 25.208(r)(2) of its rules,² without resulting in harmful interference to existing or future terrestrial services.

Within this correspondence, Boeing identifies and corrects several foundational errors and significantly flawed assumptions made by a few commenters regarding Boeing’s proposed NGSO satellite system downlink operations.³ Once corrected, the analysis methods employed by these parties support a conclusion that emission levels generated by Boeing’s NGSO satellite system in the 37/39 GHz band will be within acceptable levels to protect both existing terrestrial services and the newly created Upper Microwave Flexible Use Service (“UMFUS”).

The corrected analysis in this letter also further demonstrates the efficacy of regulating NGSO operations by enforcing limits on the equivalent power flux density (“ePFD”) resulting from the aggregate emissions of all NGSO satellites in the 37/39 GHz band. The use of ePFD

¹ See ITU Radio Regulations, Article 21.16, Table 21-4 (WRC-15).

² Section 25.208(r)(2) of the Commission’s rules allows satellite systems to operate up to the higher PFD limits maintained by the ITU to compensate for rain fade conditions.

³ Boeing also takes this opportunity to correct a non-consequential typographical error that in the final part of the equation for noise temperature that was included on page 6 of Boeing’s Further Notice comments. The equation included a “+1” term rather than a “-1” term in the noise calculation. Despite the typographical error, the correct value of “-1” was used in all calculations and in the results presented in Boeing’s comments.

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regulations, as presented in Boeing's Further Notice comments, not only ensures negligible degradation into terrestrial systems, they also effectively limit the ability of NGSO systems to increase their downlink emissions above the Commission's current Section 25.208(r) limits.⁴

Corrections to Technical Analysis of Straight Path

Straight Path Communications, Inc. ("Straight Path") suggests in its reply comments that 0.5 dB is "the threshold for a manageable rise in the noise floor due to interference from satellite" in the 37/39 GHz band.⁵ This is comparable to the 0.65 dB maximum increase in the noise floor that Boeing demonstrated in its Further Notice comments would result from the aggregate emissions of its NGSO satellites when operating in worst case conditions (*i.e.*, mis-pointing of the UMFUS receiver directly toward the satellite) and at the higher ITU PFD levels to overcome rain fade conditions.⁶

Straight Path's October 31 analysis confirms Boeing's technical findings once Straight Path's analysis is corrected for the significant errors in the calculations and assumptions that Straight Path employed. By far the most significant error in Straight Path's analysis is its use of an incorrect equation for the model of the UMFUS planar array antenna, which results in sidelobes that are twice as high as would actually result. In addition, Straight Path employs the following incorrect assumptions about the operations of Boeing's NGSO satellites in the 37/39 GHz band:

- Straight Path assumes that satellites will transmit toward Earth from all angles, including very low elevation angles, despite Boeing's assurance that its satellites will not transmit at angles below 45 degrees.
- Straight Path disregards the transient nature of NGSO interference, acknowledging, but failing to take into account that low Earth orbit satellites move quickly across the sky.
- Straight Path incorrectly assumes that transmitting satellites will always operate at peak PFD levels, rather than employing power control to increase power only in response to rain events.

⁴ Section 25.208(r) includes two sets of PFD limits, a more restrictive set in Section 25.208(r)(1) that apply only in clear sky conditions and a more lenient set (that matches the ITU PFD limits) that can be used by FSS systems to increase power to compensate for rain fade conditions. Boeing's proposed ePFD approach would incorporate both of these two concepts in one set of ePFD limits.

⁵ Reply Comments of Straight Path Communications, Inc., GN Docket No. 14-177 *et al.*, at 12 (Oct. 31, 2016) ("*Straight Path Reply*").

⁶ See Comments of The Boeing Company, GN Docket No. 14-177 *et al.*, at 36-37 (Sept. 30, 2016) ("*Boeing Comments*").

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Straight Path also makes numerous other incorrect assumptions in its reply comments, many of which are difficult to identify because, contrary to the express direction of the Commission,⁷ Straight Path did not quantify in its reply comments many of the assumptions that formed the basis of its analysis. Boeing therefore attempted to derive the assumptions that Straight Path employed, which are identified in Part 1 of the Attachment to this letter. To ensure clarity, Boeing also provides a sequence of updates in this letter that corrects Straight Path's analysis and applies Straight Path's methodology using Boeing's proposed NGSO satellite system. The analysis below is provided for an UMFUS base station receiver, but the results are equally applicable to a receiver on an UMFUS mobile device. A similar set of corrections for mobile handsets are included in Part 2 of the Attachment to this letter.

The corrected analysis clearly demonstrates that Boeing's NGSO satellite system can operate in the 37/39 GHz band without resulting in appreciable interference to terrestrial systems. Given this analysis, Commission is fully justified in moving forward with its proposal to authorize satellite end user terminals to receive signals on an opportunistic basis from NGSO satellite systems in the 37/39 GHz band using power levels that reach up to the limits maintained both by the ITU and by the FCC. Such an approach would promote the public interest by maximizing the use of scarce spectrum resources to provide broadband services to all Americans, while also being consistent with the Commission's goal of promoting UMFUS use in the 37/39 GHz band.”⁸

UMFUS Antenna Model Errors

As noted above, the most significant error in Straight Path's analyses is the use of an incorrect equation for the model of the UMFUS planar array antenna.⁹ A complete explanation of the errors in the Straight Path antenna model is provided in Part 3 of the Attachment to this letter. Once the antenna model is corrected, the antenna pattern (shown below in Figure 1) exhibits the predictable textbook behavior with first sidelobe levels of -13 dB,¹⁰ whereas the erroneous Straight Path equation results in sidelobes that are twice as high (e.g., -6 dB relative to peak versus -13 dB). This foundational error significantly alters all of Straight Path's findings.

⁷ See Use of Spectrum Bands Above 24 GHz For Mobile Radio Services, GN Docket No. 14-177, Report and Order and Further Notice of Proposed Rulemaking, FCC 16-89, ¶ 499 (Jul. 14, 2016) (“*Further Notice*” or “*Report and Order*”) (directing that “[c]ommenters should provide detailed technical studies that explicitly list the assumptions they made concerning both terrestrial and satellite operations”).

⁸ *Id.*

⁹ See *Straight Path Reply* at 11.

¹⁰ See, e.g., J.D. Kraus, *Antennas*, 2nd edition (McGraw-Hill, Inc.); at 140-141. For a quick on-line summary of expected sidelobe levels, see https://en.wikipedia.org/wiki/Side_lobe.

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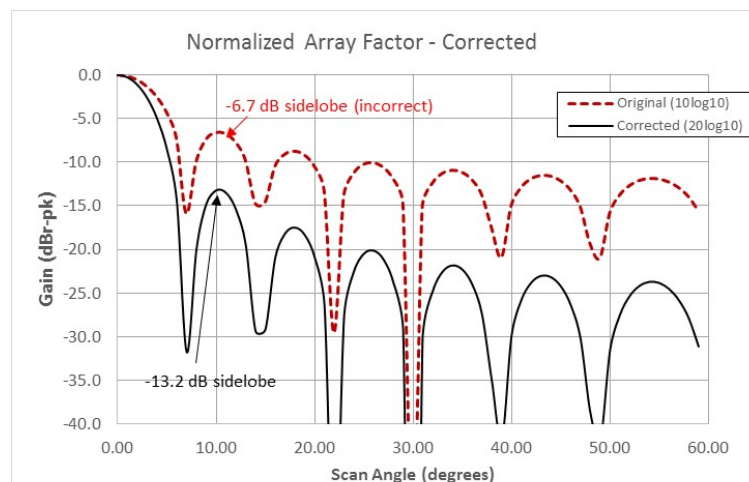


Figure 1 – Corrected Sidelobes for Straight Path Antenna Model (Original and Corrected Shown)

Figure 2 below illustrates Straight Path's original Figure 10 from its reply comments showing the predicted rise in noise floor for a 16x16 base station using an incorrect antenna model.¹¹ Figure 3 below then provides the same analysis with the calculations in the antenna model corrected.

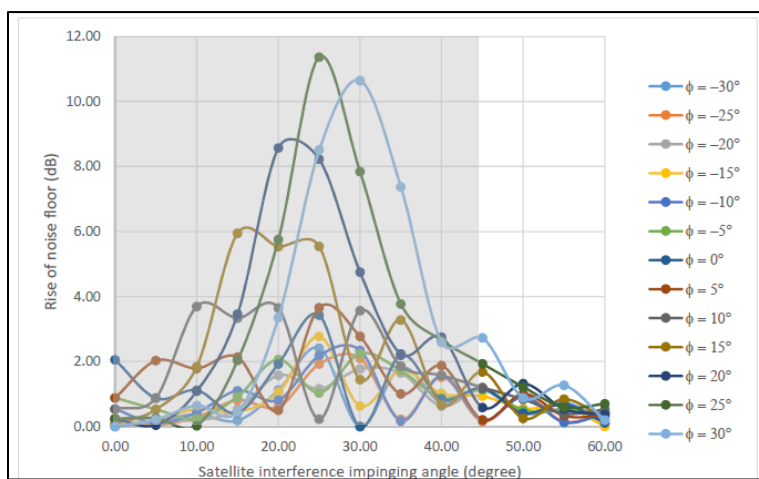


Figure 2 – Rise in Base Station Noise Floor (Straight Path Figure 10)

¹¹ See Straight Path Reply at 17

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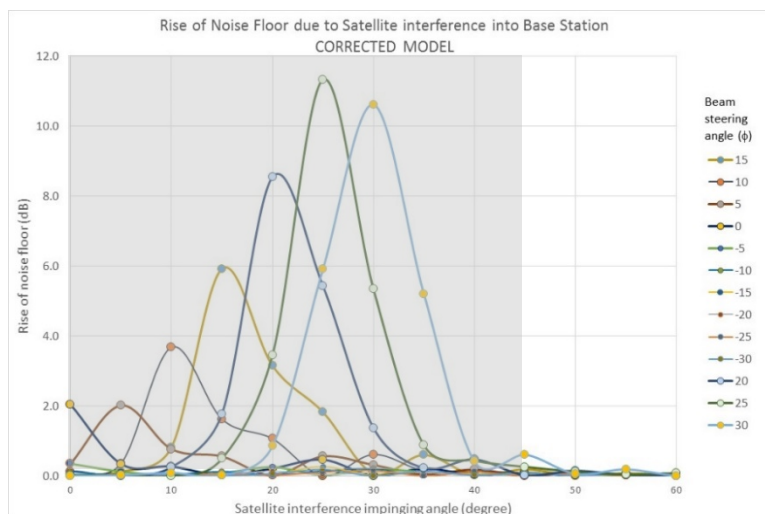


Figure 3 – Rise in base Station Noise Floor (Corrected)

Importantly, Figures 2 and 3 above have *not* been corrected with respect to any of Straight Path's erroneous assumptions regarding the operations of Boeing's NGSO satellite systems (*i.e.*, NGSO satellite movement, the use of high elevation angles, and the use of power control). Figures 2 and 3 continue to assume that satellite transmissions will arrive at very low elevation angles from fixed points in the sky and with no power control, which is not the case with Boeing's NGSO system. Nevertheless, the figures above are helpful particularly in showing the tremendous reduction in interference levels as the satellites exceed an angle of incidence of around 40 degrees.

Correcting Straight Path's Other Faulty Assumptions

As noted above, Straight Path makes several incorrect assumptions about the operation of Boeing's NGSO satellites in the 37/39 GHz band. For example, Straight Path assumes that satellites will transmit toward Earth from all angles, including very low elevation angles,¹² which disregards Boeing's assurance that its satellites will not transmit at angles below 45 degrees.¹³ Straight Path posits that satellite transmissions may reflect off buildings, mountains and other objects, and that these reflected signals may arrive in any direction into a 5G receiver.¹⁴ This argument completely disregards the significant attenuation that occurs at reflection, and the blockage of the original satellite direct line of sight signal that would also likely result in such an environment.

¹² See *id.*

¹³ See, e.g., *Boeing Comments* at 15, 18 and 34.

¹⁴ See *Straight Path Reply* at 10.

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To correct for these errors, Boeing again employs Straight Path's analysis from above involving the noise resulting from a single satellite into an UMFUS base station, but applies Boeing's planned operating conditions of NGSO satellites transmitting only from an elevation angle of above 45 degrees and using power control levels appropriate for worst-case rain fade conditions. The resulting increase in the noise floor from the transmissions of a single satellite at elevation angles above 45 degrees is less than 0.25 dB.

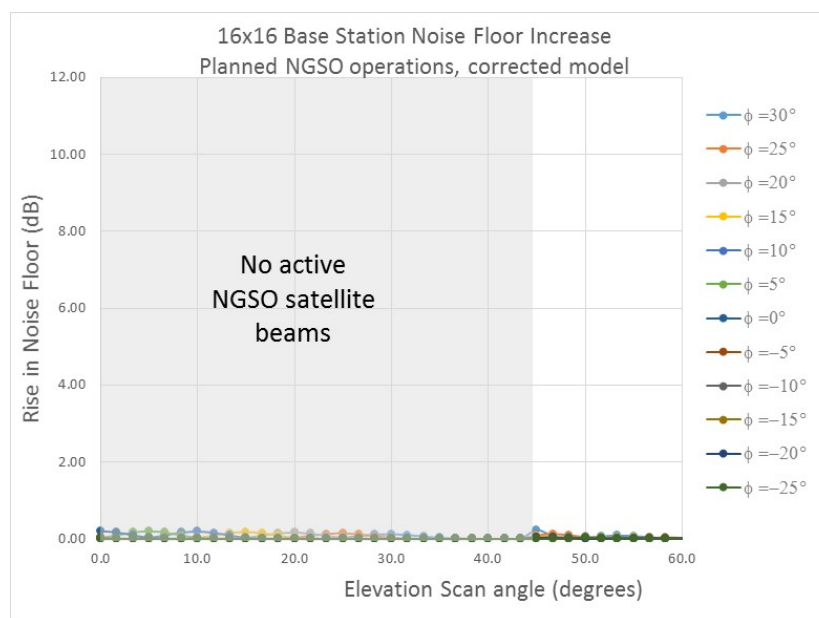


Figure 4 – Rise in Base Station Noise Floor Due to a Single Boeing NGSO Satellite in Rain Fade

These corrected results are well within the manageable degradation levels referred to by Straight Path and are fully consistent with Boeing's prior ePFD results, which show noise floor degradations of less than 0.65 dB resulting from Boeing's entire constellation. The aggregate ePFD levels from the entire constellation of Boeing's NGSO satellites are provided below in Table 1. The interference scenario involving an UMFUS base station was captioned as Case 3a in Boeing's Further Notice comments and clearly shows a 0.65 dB increase in the noise floor for 99.5 percent of all possible beam steering cases from the base station, and only during infrequent high-rain fade events.¹⁵

¹⁵ See Boeing Comments at 37.

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Scenario	5G receiver	Location	ePFD (dBW/m ² /MHz)		Link degradation (noise increase), dB	
			99%	99.5%	99%	99.5%
3a - Base Stations (random ptg)	64 elem (8x8)	New York	-116.5	-115.0	0.42	0.55
	256 elem (16x16)		-125.1	-120.4	0.24	0.65
	1024 elem (32x32)		-135.0	-131.2	0.10	0.23
3a - Base Stations (random ptg)	64 elem (8x8)	Miami	-116.4	-115.0	0.42	0.60
	256 elem (16x16)		-127.0	-121.5	0.15	0.50
	1024 elem (32x32)		-135.2	-132.0	0.10	0.19

Table 1 – Results of ePFD and Interference Degradations into UMFUS Receivers

Straight Path again asserts in its reply comments that FSS downlink interference, even at 0.5 dB noise floor levels, will have far-reaching impacts to 5G deployment plans and operating capacity. Straight Path’s rhetoric largely repeats Straight Path’s prior arguments of a loss of UMFUS cell ‘range’ or size, and adds another hypothetical discussion of a nationwide loss of potential UMFUS capacity.¹⁶ In doing so, Straight Path completely neglects the transient nature of NGSO interference and the worst-case rain fade assumptions employed in Boeing’s analysis.

Although Straight Path acknowledges that low Earth orbit satellites are in motion and cause only temporary degradations,¹⁷ it fails to account for this in its hypothetical capacity impact assessments. Further, Straight Path assumes that satellites will *always* operate at peak transmission levels, rather than employing power control to increase power only in response to rain events. As a result, Straight Path’s calculations of capacity and other impacts to UMFUS deployment appear to assume that this degradation will somehow be present simultaneously in all areas of the United States.¹⁸

To correct these bedrock misconceptions, Boeing presents below an accurate estimated capacity impact for an UMFUS system deployment, which correctly incorporates the extremely low probability of transient interference degradations from NGSO transmissions. As shown in Table 2, Boeing employed the calculated worst-case link degradations of 0.65 and 1.0 dB and applied them to the corrected assumptions that these degradations will occur in less than 1 percent of the possible pointing geometries, and less than 10 percent of the time, *i.e.*, only when heavy rain fade occurs. In making these assumptions, Boeing’s analysis still leaves in place several very conservative assumptions (assumptions that produced the degradations of up to 0.65 dB), such as decorrelated clear-sky path conditions to UMFUS receivers in areas where satellites are using higher power to compensate for rain fade.

¹⁶ See *Straight Path Reply* at 19.

¹⁷ See *id.* at 19 (acknowledging that LEO satellites “are moving at an orbit speed of 128 minutes per cycle”).

¹⁸ See *id.* at 16, 18-19.

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PARAMETER	UNITS	I/N=-8	I/N=-6	COMMENT
Link degradation due to satellite interference	dB	0.65	1.0	Rise in noise floor, satellite in view in heavy rain fade
Probability of satellite interference (as calculated in heavy rain fade)	%	1.0%	1.0%	99% of the time the degradation is <u>less</u> than above
Probability of rain fade	%	10.0%	10.0%	90% of the time it is <u>NOT</u> raining
Total Probability of degradation event	%	0.10%	0.10%	Total % of time degradation may exist
Nominal spectral efficiency (no interference)	bps/Hz	2.0	2.0	Average - can be lower or higher
Capacity decrease due to degradation	%	7.9%	12.1%	During the transient ONLY, at certain spots with high rain
Total system capacity impact	%	0.0079%	0.0121%	Very small
Percent of design capacity achieved	%	99.992%	99.988%	Very high

Table 2 – UMFUS Capacity Achieved During Transient NGSO Interference

Table 2 above shows that the probability of an UMFUS receiver experiencing a worst case link degradation (noise floor increase) of 0.65 dB or 1.0 dB is only 0.1 percent of the time, and the effective impact on system capacity would be less than 0.01 percent, which is three orders of magnitude less than estimated by Straight Path. In other words, UMFUS deployed systems will still achieve more than 99.9 percent availability of their planned design capacity in the presence of satellite downlink transmissions from Boeing’s NGSO satellites (and the comparable NGSO systems of other operators) when operating pursuant to Boeing’s proposed ePFD limits. Therefore, the Commission should appropriately disregard the flawed analysis that was included in Straight Path’s reply comments.

Use of an ePFD Regulatory Approach

As noted above, Boeing has proposed that the Commission adopt limits on aggregate satellite emissions using an ePFD approach, which is the same approach that the Commission employs to regulate aggregate NGSO satellite system emissions in the Ku-band. Samsung appears to misconstrue Boeing’s ePFD proposal, claiming that “Boeing recommends the PFD be reduced by 3 dB to account for UMFUS mobile users experiencing stronger interference from an aggregate of satellites.”¹⁹ This is an apparent reference to Boeing’s recommendation of an ePFD level of -108 dBW/m²/MHz for an NGSO constellation into an UMFUS mobile receiver. The nature of PFD and ePFD limits are inherently different and therefore a proposed PFD level cannot be subtracted from a proposed ePFD level (*i.e.*, -108 minus -105) to produce a valid comparison.

Straight Path similarly suggests that ePFD is too complicated an approach and recommends that the Commission instead endorse the flawed approach of “aggregating interference from multiple satellites by adding the PFD levels from multiple satellites with overlapping coverage.”²⁰ Straight Path incorrectly argues that this simplistic approach “is

¹⁹ See Reply Comments of Samsung Electronics America, Inc. and Samsung Research America, GN Docket No. 14-177 *et al.*, at 17, Section C (Oct., 31, 2016) (“*Samsung Reply*”).

²⁰ See *Straight Path Reply* at 21.

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equivalent to the ePFD approach as Boeing proposed with arbitrary receivers and random pointing direction.”²¹

Nothing could be further from the truth. Satellite signals, arriving from point sources located more than 1,000 kilometers (one million meters) away, which are usually separated by 1,000 kilometers, will arrive as plane waves from different angles and cannot physically be combined to aggregate with equal power into the beam of a directive antenna. Although ePFDs are very different from PFDs, their calculation and methodology is simple and robust and their use guarantees the correct performance for an arbitrary number of satellites regardless of their orbit or angle of arrival. This is why the Commission appropriately employed an ePFD approach to govern the operation of NGSO satellites in the Ku-band to ensure the protection of incumbent systems in that spectrum.

Straight Path also argues that an ePFD approach may “impose limitations on the receivers and antenna pointing directions for 5G services.”²² This is incorrect because ePFD regulations restrict only satellite operations, not UMFUS systems. Although an ePFD approach requires the use of reference UMFUS antennas to calculate the ePFD limits, this approach places no limits on the types or configurations of the antennas used by actual terrestrial UMFUS networks. Instead, the ePFD regulations provide additional regulatory certainty that interference levels are very low (much lower than single-beam allowable PFDs) and transient (occurring for an extremely small percentage of the time). Such regulations also severely limit how NGSO systems may operate multiple satellites with multiple beams, ensuring that interference to terrestrial systems is reliably limited. The use of single beam and single satellite PFD limits, including those currently in place, cannot provide such certainty.

Response to T-Mobile’s UMFUS Handset Discussion

In its Further Notice Reply comments, T-Mobile does not dispute that an ePFD approach is appropriate for interference calculations involving multiple NGSO satellites, but T-Mobile questions some of Boeing’s assumptions regarding mobile user handset antennas for UMFUS devices.²³ In particular, T-Mobile is concerned that an UMFUS device with multiple small antenna arrays on different sides and edges of the device may experience increased interference from satellite downlink transmissions, in part because the additional antennas may increase the total number of satellites within the field of view of the device.²⁴

²¹ *Id.*

²² *Id.*

²³ Reply Comments of T-Mobile, GN Docket No. 14-177, at 16 (Oct. 31, 2016) (“*T-Mobile Reply*”).

²⁴ *Id.* at 17.

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T-Mobile's concern is unjustified for two reasons. First, the ePFD analysis that Boeing included in its Further Notice comments already assumed that the victim UMFUS device would simultaneously receive unobstructed transmissions from all of the transmitting NGSO satellites within the visible field of view above the horizon. Therefore, an UMFUS device with additional antenna arrays facing in additional directions could not receive interference from additional satellites because no additional satellites transmitting above the horizon would exist.

Second, Boeing's ePFD analysis already assumed that the antenna array on the mobile UMFUS device would be pointing directly at a satellite, rather than at its intended base station. As a result, any other orientation of the UMFUS antenna array could only reduce the potential for interference, rather than increase it. To this end, Figure 5 illustrates a potential handheld UMFUS device with element arrays laid out in manner similar to that described by T-Mobile. Though there are obvious space limitations in compact handheld devices, the beams are intended to provide coverage of largely independent sectors to cover the omnidirectional (4π steradian) field of view of the device with separately steered high-gain beams. The noise floor degradation into each of the beams is independent, and are listed in Figure 5.

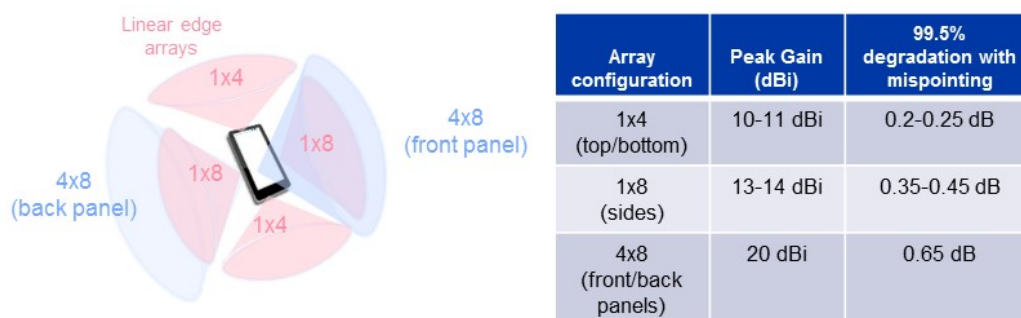


Figure 5 – Potential Degradation to UMFUS Device With Multiple Array Antennas

All of the satellites within the visible field of view (above the horizon) have already been included in these ePFD and noise floor degradation calculations – no more satellites can be seen by adding more beams from various faces of a handset device. T-Mobile's concerns that multiple beams employed by an UMFUS end user device may experience more interference is unfounded and such devices are already envisioned and included by the ePFD regulations proposed by Boeing.

Corrections to Technical Analysis of Samsung

Samsung includes in an Appendix to its Further Notice reply comments various fixed PFD levels which might be employed in regulations applicable to satellite downlink

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transmissions in the 37/39 GHz bands.²⁵ As noted previously, Samsung suggests that a I/N level of -6 dB (with resulting noise floor increases of 0.97 dB) as an acceptable interference level in modern 5G systems, which is a level more commonly utilized in many interference situations. In generating its recommendations for satellite downlink PFD limits in the 37/39 GHz band, however, Samsung employs calculations that use the 28 GHz as the operating frequency band.²⁶ The 28 GHz band is used by satellite networks as an uplink band and not as a downlink band. As a result, the PFD levels suggested in the Samsung Appendix are incorrect. Corrected values are shown in Table 3 below and demonstrate that, using Samsung's recommended PFD limits, mobile stations can withstand satellite downlink PFD transmission levels of -105 dBW/m²/MHz when the mobile station is mis-pointed directly at the satellite.

5G UMFUS Unit Type	MS				TS		
Array Configuration	1x4 or 2x2	1x6 or 2x3	1x8 or 2x4	4x4	4x4	4x8	8x8
Total Elements	4	6	8	16	16	32	64
GRx (dBi)	10	11.8	13	16	16	19.1	22.1
GRx roffoff (dBr)	0	0	0	0	0	0	0
Absolute Gain (dBi)	10	11.8	13	16	16	19.1	22.1
NF (dB)	7	7	7	7	6	6	6
Frequency (GHz)	28 39	28 39	28 39	28 39	28 39	28 39	28 39
Noise Floor in front of mobile receiver antenna (dBW/MHz)	-147.0	-148.8	-150.0	-153.0	-154.0	-157.1	-160.1
PFD limit (dBW/m2/MHz)	-102.6 -99.7	-104.4 -101.5	-105.6 -102.7	-108.6 -105.7	-109.6 -106.7	-112.7 -109.8	-115.7 -112.8

Table 3 – Samsung's PFD and Noise Floor Analyses (Corrected)

This said, Boeing believes that it is inappropriate to use a fixed analyses performed at the peak gain of the receiver to determine interference limits. As discussed in the opening sections of this letter, a far more accurate approach is the use of ePFDs, which, as detailed in the figure above, would result in aggregate satellite downlink transmissions in the 37/39 GHz band that are below the levels suggested by Samsung in its worst-case fixed point analysis, even after Samsung's analysis is corrected to consider satellite transmission conditions in the 37/39 GHz band.

Corrections to CTIA's Reply Comments

In its reply comments, CTIA mistakes measurements performed on satellite earth station gateways operating in the uplink direction in the 28 GHz band as being applicable to satellite

²⁵ See *Samsung Reply*, Attachment 1, at 16-18.

²⁶ See *id.* Attachment 1, at 18, Table in section D.

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downlink transmissions in the 37/39 GHz band.²⁷ CTIA references Nokia's claim that it conducted measurements showing that *earth station gateway transmissions* in the 28 GHz band were 20-30 dB higher than the adopted limits.²⁸ CTIA then claims that these findings "show that *satellite transmissions*' emission levels are higher and impact a greater angular area as compared to the adopted PFD limits" for the 37/39 GHz band.²⁹ CTIA compounds its error by asserting that "Nokia's real-world measurements demonstrate that the assumptions made by Boeing when establishing its modeling of the interference environment for the 37.5-40 GHz band will likely require measurements rather than simply modeling before they can be relied upon by the Commission."³⁰

Obviously, localized measurements of *uplink* emissions from satellite earth stations at distances of less than 200 meters have no bearing on the potential *downlink* emissions encountered from orbiting satellites located some 1,200 kilometers away from UMFUS receiving equipment. CTIA's assertions are therefore specious. Further, as Boeing explained in its reply comments, Nokia's measurements were taken in the near-field of the antennas being measured and were incorrectly compared to analysis that was intended to be based on far-field conditions. Moreover, orbiting satellites and UMFUS equipment are in the far-field relative to each other and the analyses presented by Boeing are fully valid and applicable to satellite downlink and UMFUS receiver interference conditions.

CTIA also incorrectly characterizes Boeing's spectrum sharing analyses, asserting that "the isolation expected by Boeing in its analysis for mobile base stations from satellite downlink transmissions requires that base stations not point at elevation angles above the horizon."³¹ As Boeing clearly explained in its Further Notice comments, Boeing's analysis included operational conditions that included an UMFUS base station with beams pointing up to 60-degrees skyward (case number 3a: random base station pointing) and with an UMFUS base station pointing upwards 51.7 degrees towards users within a close building (case number 3b: 3GPP Urban Micro scenario). In each case, the resulting UMFUS link degradations ranged from 0.6 dB down to less than 0.1 dB with 99.5% confidence, which are well within acceptable levels.

²⁷ See Reply Comments of CTIA, GN Docket No. 14-177 *et al.*, (Oct., 31, 2016) at 13-14 ("*CTIA Reply*").

²⁸ See *id.*

²⁹ *Id.*, at 14 (*emphasis added*).

³⁰ *Id.* at 14.

³¹ *Id.*

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CTIA also incorrectly asserts that “Boeing also assumes that all terrestrial base stations would have some shielding from high powered satellite earth stations.”³² This is apparently in reference to T-Mobile comments rather than to Boeing’s analyses. Boeing has never assumed that UMFUS base stations would employ any form of shielding. Boeing did suggest, however, that UMFUS base stations transmitting upwards toward tall buildings may benefit from the natural shielding that the buildings may provide. T-Mobile also agreed, acknowledging that “[t]his may be true for dense city centers with tall buildings.”³³ Therefore, not only was CTIA confused about the issue being discussed, it also failed to acknowledge that Boeing and T-Mobile were in agreement regarding the likely outcome.

Nokia Questions

Finally, Nokia raised a number of questions in its reply comments regarding the assumptions that Boeing employed in the extensive technical analysis that it included in its Further Notice comments.³⁴ Boeing provides answers to these questions in Part 4 of the Attachment to this letter.

Conclusion

Boeing’s submissions in this proceeding have used explicit technical assumptions and detailed analysis to fully demonstrate that the operation of NGSO satellite systems in the 37/39 GHz band using power levels up to those maintained by the ITU and by the Commission in Section 25.208(r)(2) of its rules will not result in appreciable interference to UMFUS systems. Further, the use of an ePFD approach will ensure that the aggregate emissions of all NGSO satellites operating in the 37/39 GHz band will adequately protect terrestrial systems. The proposed operation of NGSO satellites to serve satellite end user terminals in the 37/39 GHz band is therefore consistent with the Commission’s identification of the 37/39 GHz band as primarily available for UMFUS.

No party has presented a legitimate challenge to Boeing’s technical analysis and findings. Further, the analysis of the aforementioned commenting parties included significant errors and erroneous assumptions, which Boeing has addressed in this letter. Therefore, in order to further the public interest and maximize the use of millimeter wave spectrum to provide broadband services to all consumers, the Commission should authorize NGSO satellites to operate in the 37/39 GHz band in order to provide broadband services on an opportunistic basis to satellite end user receivers.

³² *Id.* at 15 (citing Comments of T-Mobile USA, INC., GN Docket No. 14-177 *et al.*, at 29 (Sept. 30, 2016) (“*T-Mobile Comments*”)).

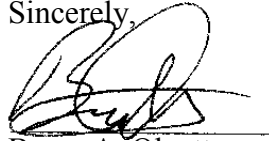
³³ *T-Mobile Comments* at 29.

³⁴ See Reply Comments of Nokia, GN Docket No. 14-177 *et al.*, at 4-5 (Oct., 31, 2016).

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Thank you for your attention to this matter. Please contact the undersigned if you have any questions.

Sincerely,

A handwritten signature in black ink, appearing to read "Bruce A. Olcott", written over a horizontal line.

Bruce A. Olcott
Counsel to The Boeing Company

Attachment

Part 1 – Straight Path Assumptions

PARAMETER	VALUE	COMMENTS
Mobile Handset size	4x8 (32 elements)	
Mobile Handset peak gain	20.0 dBi	5 dBi element gain Straight Path no longer has included beam forming losses, which is in conflict with its prior analysis. ¹
Mobile Handset Noise Figure	7.0 dB	Straight Path's handset noise figure is lower than what is specified by 3GPP participants and many equipment manufacturers. 3GPP references use higher values from 10 dB (high performance) to 13 dB (baseline). ²
Background temperature	290K	
Base station size	16x16 (256 elements)	
Base station peak gain	32.1 dBi	8 dBi element gain Straight Path no longer has included beam forming losses, which is in conflict with its prior analysis. ³
Base station Noise Figure	5 dB	3GPP references use 7 dB for BS noise figures ⁴
Background temperature	290K	
ITU PFD Limits (and FCC in rain fade) dBW/m ² /MHz	25 < θ ≤ 90 deg: -105 5 < θ ≤ 25 deg: -120+(3/4)*(θ -5) θ ≤ 5 deg: -120	Elevation angle (θ); per ITU Article 21.16, Table 21-1 and 47 CFR § 28.208(r)(2) during rain fade These are maximum regulatory limits for a single radiating beam; however, Boeing's system transmits only from elevation angles above 45 degrees
FCC PFD Limits (clear sky conditions) dBW/m ² /MHz	25 < θ ≤ 90 deg: -117 5 < θ < 25 deg: -132+(3/4)*(θ -5) θ ≤ 5 deg: -132	Elevation angle (θ); per 47 CFR § 25.208(r)(2) Same comment as above; noting that the current FCC rules allow for the higher limits during rain fades

¹ See Ex Parte Letter of Straight Path Communications, Inc., GN 14-177 *et al.*, Appendix II, at 6 (June 20, 2016) (“*Straight Path June Letter*”) (providing link budgets showing 2 dB “antenna feed network losses” for handsets and 3 dB losses for base stations).

² See *Study on Channel Model for Frequency Spectrum Above 6 GHz*, 3GPP TR 38.900 v14.1.0, § A.2, Tables A.2.1-1 through A.2.1-3 (Sept. 2016) (“*3GPP Channel Model Study*”) (providing UE receiver noise figure); *also see WF on UE Receiver Noise Figures*, 3GPP R1-165742, available at http://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_85/Docs/R1-165742.zip.

³ See *Straight Path June Letter*, Appendix II (link budgets showing 2 dB “antenna feed network losses” for handsets and 3 dB losses for base stations).

⁴ See *3GPP Channel Model Study*, § A.2, Tables A.2.1-1 through A.2.1-3 (BS receiver noise figure) (identifying for further study that only “Extreme Long Range” base stations are suggested as having a noise figure of 5 dB).

Part 2 – Updated Handset Interference Analyses Curves

As noted in the accompanying letter, Straight Path’s October 31 analysis used an incorrect equation for the model of the UMFUS planar array antenna, along with a number of incorrect assumptions regarding the operation of Boeing’s NGSO satellites in the 37/39 GHz band. Boeing provides an analysis below using Straight Path’s methodology to show the potential impact of Boeing’s NGSO system to an UMFUS mobile device with the errors and assumptions corrected. Figure 3-1 below depicts Straight Path’s Figure 7 from its October 31 reply comments without any corrections.⁵

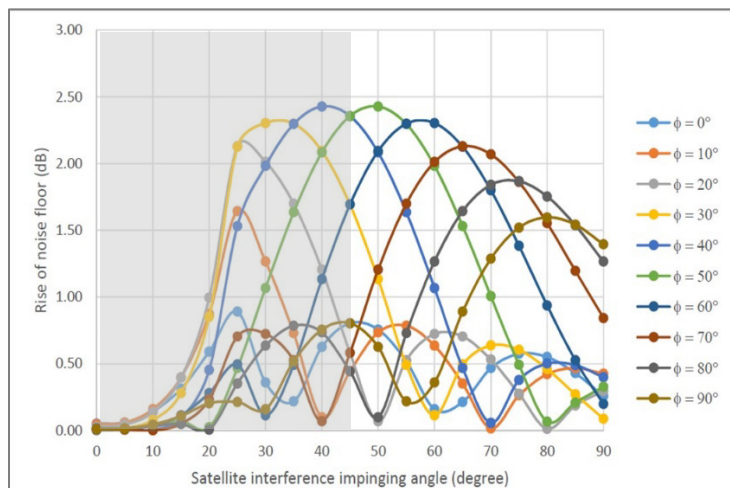


Figure 3-1 – Rise in Mobile Station/Handset Noise Floor (Straight Path Figure 7)

Figure 3-2 below then depicts this same analysis but with the antenna model corrected and employing appropriate assumptions regarding the operation of Boeing’s NGSO system including having satellites in motion and transmitting to the ground only from elevation angles above 45 degrees and using power control to increase power in response to rain fade.

⁵ See *Straight Path Reply* at 11.

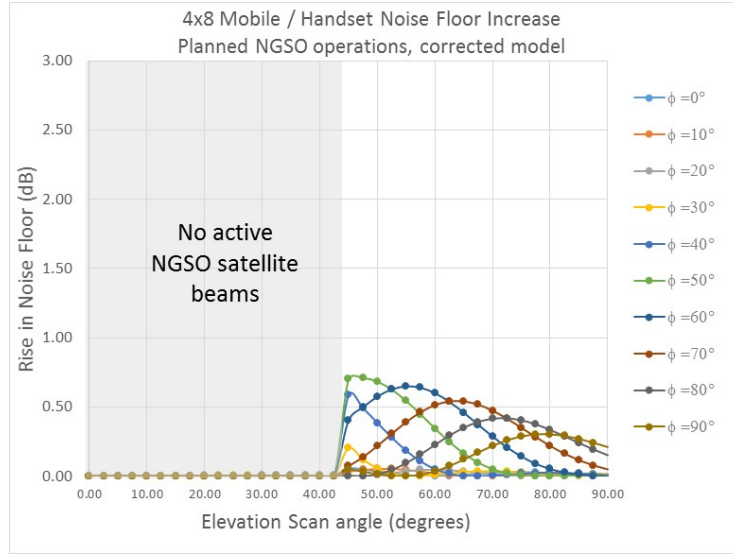


Figure 3-2 Rise in Handset Noise Floor (corrected)

The increase in the noise floor for an UMFUS mobile device resulting from the transmissions from a single satellite at elevation angles above 45 degrees is less than 0.70 dB. This compares favorably to Boeing’s ePFD results shown in Boeing’s Further Notice comments, Table V-6, showing 0.64 dB in Case 1 for mis-pointed handsets.⁶ Again, these results would only pertain for a device temporarily searching for a correct base station, for the small percentage of the time when an NGSO satellite is in the view at the peak of the antenna gain, and during worst-case rain fades (e.g., well less than 0.05% of the time).

Part 3 – Corrected Antenna Model

Straight Path’s reply comments use the following equation as a representation of the gain pattern of a planar array antenna pattern for an UMFUS device measured along the elevation direct aligned with element columns:⁷

$$A(\theta) = 10 \log_{10} \left(\left| \frac{\sin \left(\frac{N\pi}{2} (\cos\theta - \cos\phi) \right)}{\sin \left(\frac{\pi}{2} (\cos\theta - \cos\phi) \right)} \right| \right) + G_{E,max} + A_{E,V}(\theta)$$

This equation, though in a familiar form for a linear array of elements, is incorrect in the first term. The array factor power gain of a linear array of N elements, spaced at $d=\lambda/2$, and steered to direction ϕ relative to endfire, is given by:⁸

⁶ See Comments of The Boeing Company, GN Docket No. 14-177 et al., at 37, Table V-6 Case 1 (Sept. 30, 2016).

⁷ Reply Comments of Straight Path Communications, Inc., GN Docket No. 14-177 et al., at 11 (Oct. 31, 2016) (“Straight Path Reply”).

⁸ See, e.g., R. Mailloux, *Phased Array Antenna Handbook*, (Artech House), Section 2.2, at 72; J.D. Kraus, *Antennas*, 2nd edition (McGraw-Hill, Inc.); at 140-141.

$$\text{Normalized Array factor (complex amplitude/phase)} \quad f(\theta) = \frac{\sin\left(\frac{N\pi}{2}(\cos(\theta) - \cos(\phi))\right)}{N\sin\left(\frac{\pi}{2}(\cos(\theta) - \cos(\phi))\right)}$$

$$\text{Normalized Array factor (power gain)} \quad F(\theta) = 10\log_{10}(|f(\theta)|^2) = 20\log_{10}(|f(\theta)|)$$

In order to compute the correct antenna power gain of the array, it is necessary to use either $10 \cdot \log_{10}(\quad)$ of the magnitude squared, or $20 \cdot \log_{10}(\quad)$ of the absolute value of the antenna array factor. A corrected version of the array gain, using Straight Path's notation would be:

$$A(\theta) = 10\log_{10}(N) + 20\log_{10}\left(\left|\frac{\sin\left(\frac{N\pi}{2}(\cos(\theta) - \cos(\phi))\right)}{N\sin\left(\frac{\pi}{2}(\cos(\theta) - \cos(\phi))\right)}\right|\right) + G_{E,max} + A_{E,V}(\theta)$$

Part 4 – Answers to Nokia Questions

In its Reply Comments, Nokia raised a number of questions regarding the assumptions that Boeing employed in the extensive technical analysis that it included in its Further Notice comments.⁹ The following points respond to each of Nokia's questions.

1. Satellite Altitude: The altitude of the Boeing satellites analyzed are 1,000 and 1,200 kilometers, representing the mixed inclination and altitude constellation included in Boeing's V-band application.¹⁰ All satellites included operate in a low Earth orbit in a non-geostationary satellite orbit ("NGSO"). Boeing's analysis did not include any geostationary satellites.
2. Tilt of UE or AP/Base Stations: For UMFUS end user terminals ("UEs"), the planar arrays represented in Case 1 are all mis-pointed directly at the satellite. In other words, the mobile handset device has a physical up-tilt that aligns it with the downward transmission path of an NGSO satellite. The electrical beam also has maximum gain steered at this tilted broadside. For UMFUS base stations, the AP sector planar arrays are pointed with broadside towards the horizon (no downtilt or uptilt). There is no 'time varying' physical tilt associated with any UMFUS equipment.
3. Satellite Antenna Gain Towards UMFUS Equipment: There is no satellite antenna gain assumed in Boeing's analysis, as the analysis uses the received power flux density (PFD) of a satellite signal arriving at the point on the earth. The PFD level from each satellite is the maximum PFD generated by Boeing's satellite spot beams, when power control is applied for rain fade conditions. In spite of the rain fade condition, the PFD on the earth is calculated assuming direct line of sight ("LOS") to the UMFUS receiver with slant range path loss (free space loss) only.

⁹ See Reply Comments of Nokia, GN Docket No. 14-177 *et al.*, at 4-5 (Oct. 31, 2016).

¹⁰ See The Boeing Company Application for Authority to Launch and Operate a Non-Geostationary Low Earth Orbit Satellite System in the Fixed Satellite Service (S2966), SAT-LOA-20160622-00058 (filed June 22, 2016).

4. Satellite Power Density: The operational transmit PFD levels used by the satellite are varied by range and by location on the Earth depending on rain fade predicted in the associated ITU-R P618-12 propagation models. In all cases, the signal ranges from clear sky to less than -105 dBW/m²/MHz as received on the surface of the Earth with no rain loss.
5. Satellite Bandwidth and Co-channel Interference: The bandwidth of the satellite signals spans up to 5 GHz. Power flux densities are used in the interference analysis and the densities are assumed to be “co-channel” with UMFUS signals as they entirely span planned UMFUS channel bandwidths of 100 to 500 MHz. The relative power levels of satellite signals versus the UMFUS signals are available, but not employed in Boeing’s analysis. Instead, the analysis employs PFD levels to consider the interference-to-noise (I/N) ratios and the resulting increases to the noise floor.
6. Propagation Model: As indicated in Boeing’s Further Notice comments, Boeing used the ITU-R P.618-12 rain loss model to compute the necessary levels for power control and to determine the amounts by which to increase the power of satellite transmissions. The signal propagation from the satellite to any UMFUS receiver, however, is computed as pure direct LOS with free-space loss only. There is no propagation model used for UMFUS signals as the downlink interference metric only computes increases in UMFUS receiver noise floor due to satellite signals.
7. Number of Satellites and Worst-case/Other Statistics: All satellites in Boeing’s proposed NGSO system (2,956 satellites) are included in the interference analysis. As Boeing’s Further Notice reply comments indicated, only active satellites that are above a 45 degree elevation angle radiate beams at the Earth location, whereas all other satellites visible above the horizon radiate beams in other directions and their emissions are included using appropriate range losses and sidelobe levels. The statistics shown in Boeing’s Further Notice comments, Table V-6 and Figures V-4 and V-5, are taken from the entire cumulative probability distribution of interference into the receiver. To limit the potential interference into operational UMFUS systems, only the 95%-tile or higher results are shown for consideration in these discussions.
8. UMFUS Antenna Gain Parameters: Boeing derived UMFUS antenna gain parameters using the 3GPP channel model antenna modeling recommendations for planar arrays. Table V-4 of Boeing’s Further Notice comments shows the planar array configurations and peak gains derived for these receiver devices. Noise figures used by Boeing are lower than those included in either 3GPP recommendations.